Vol. 84 (1993) *ACTA PHYSICA POLONICA A* No. 1

Proceedings of the VI International School on Magnetism, Białowieża '92

ELECTRONIC PROPERTIES OF HIGH-TEMPERATURE SUPERCONDUCTOR $DyBa_2Cu_3O_7$ FROM CRITICAL FIELDS AND SPECIFIC HEAT STUDIES

A. Kolodziejczyk, A. Kozlowski, J. Chmist, R. Zalecki, T. Ścieżor, Z. Tarnawski, and W.M. Woch

Department of Solid State Physics, Academy of Mining and Metallurgy
Al. Mickiewicza 30, 30-059 Kraków, Poland

The lower and upper critical fields, as well as the specific heat were measured as a function of temperature for good quality $DyBa_2Cu_3O_7$ high-temperature superconductor in the vicinity of superconducting transition temperature $T_c = 91.2$ K. The number of superconducting and normal state electronic quantities were determined basing on the Ginzburg–Landau–Abrikosov–Gorkov theory. It is argued that on the basis of this BCS-like theory one can describe the superconducting properties and, in combination with some information on the electronic structure, also the magnetic properties of high-temperature superconductors.

PACS numbers: 74.70.–b, 76.30.–v

1. Introduction

The pairing mechanism responsible for high-temperature superconductivity is still not determined and many theoretical models have been proposed to explain physical properties of the high-temperature superconductors (HTS). There is a number of experimental data suggesting that the new superconducting oxides are the BCS-type superconductors [1–6] with a strong electron–phonon or other coupling, anisotropy of physical characteristics and very short coherence lengths. At present, there is a tendency to measure some important characteristics of HTS's more carefully in order to compare their physical behavior with predictions of theoretical approaches and to indicate a possible pairing mechanism and magnetic interactions.

In this paper we present the specific heat measurements and a new method of determining the lower critical field $H_{c1}(T)$ from the a.c. susceptibility in an applied external field. Also we measured the magnetoresistance in order to find the temperature dependence of the upper critical field $H_{c2}(T)$. The purpose of this paper is to compare the data with the predictions of the BCS-like Ginzburg–Landau–Abrikosov–Gorkov theory (GLAG).

2. Experimental

The $DyBa_2Cu_3O_7$ specimen was used to measure the specific heat and the a.c. susceptibility as a function of magnetic field and temperature in order to determine the electronic specific heat coefficient γ and the lower critical field $H_{c1}(T)$. Resistivity and magnetoresistivity was also measured in order to find the transition temperature and the temperature dependence of upper critical field $H_{c2}(T)$. The a.c. susceptibility measurements were performed for bulk rod-like shaped specimens as well as for the powdered specimen in order to elucidate the effect of grains and porosity (granular effect).

The specimens were prepared by our standard sintering procedure [7], but a special care was taken to regrind the sintered material a few times in the agate ball-mill in order to reach as homogenized material as possible. In our opinion, this subsequent and several-times regrinding together with good and full calcination of the material are the crucial points to get the good quality of specimen. The Dy specimen chosen to the present experiments is one of the best quality specimens we ever managed to prepare in our sintering technology. The very sharp resistive transition to superconducting state and the very abrupt drop of a.c. susceptibility below T_c (diamagnetic response) are shown in Fig. 1 for $DyBa_2Cu_3O_7$. The width of

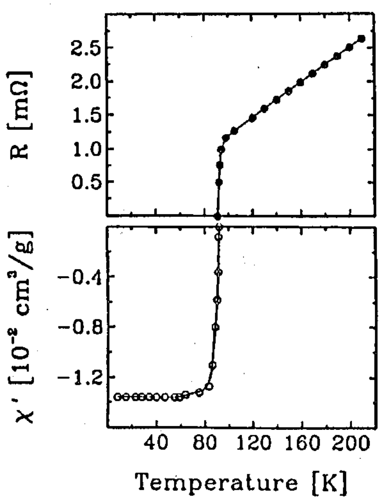

Fig. 1. The temperature dependence of the resistance (upper part) and a.c. susceptibility (lower part) of $DyBa_2Cu_3O_{\sim 7}$.

transition temperature is very small $\Delta T = T_{90\%} - T_{10\%} = 0.7\ \mathrm{K} \pm 0.1\ \mathrm{K}$, where $T_{90\%}$ and $T_{10\%}$ are the temperatures at which 90% and 10% of the lowest-temperature normal-state resistance are detected, respectively. The superconducting transition temperature is $T_c = 91.2$ K and 91.0 K measured resistively and by a.c. susceptibility, respectively.

The resistance and magnetoresistance were measured with about 1% accuracy by the standard four-point a.c. resistance method at the frequency of 6.72 Hz, for applied current of 2–3 mA rms, for rod-like shaped specimens with dimensions $2\times2\times15$ mm^3, mainly within the range of liquid nitrogen temperatures close to T_c and in the helium cryostat with the Pt-100 thermometer. The magnetic field was applied by the conventional copper liquid-nitrogen-cooled solenoid for small fields up to 0.35 T ($\sim$ 45 A m^{-1}) or by the Oxford-Instruments superconducting coil. The magnetoresistance measurements were performed versus temperature at the given applied magnetic field and versus magnetic field while sweeping temperature.

The in-phase a.c. susceptibility χ' was measured by mutual inductance bridge operating at the frequency of 237 Hz. The in-balance bridge signal in the secondary coils loaded with the given specimen was detected by the phase-sensitive lock-in amplifier. The sensitivity of the bridge as calibrated with Er_2O_3 is about 4×10^{-6} cm^{-3} μV^{-1} g^{-1}. In order to determine the lower critical field as a function of temperature the a.c. susceptibility as a function of applied magnetic field and temperature was measured for the bulk as well as the powdered specimen of $DyBa_2Cu_3O_7$.

The specific heat of about 500 mg of $DyBa_2Cu_3O_7$ was measured by two methods, i.e. by the semi-adiabatic pulse heat technique and by the continuous heating technique and within temperature range from 50 K to 250 K. More details about our calorimeter and cryostat were described in [8] and about present experiments on specific heat in [9].

3. Results and their analysis

3.1. Critical fields

The experimental results of resistance and a.c. susceptibility as a function of applied magnetic field need additional comments in connection with the specific features of HTS. It has already been established that the temperature dependencies of the lower and the upper critical fields measured for bulk polycrystalline specimen are very much affected by the so-called granular effect [10]. It is associated with the fact of the granular structure of HTS due to very short coherence length in comparison to the grain diameter and the intergrain boundary thickness. Thus, an individual HTS consists of superconducting grains separated by non-superconducting intergrain barriers which play a role of tunnel junctions. Hence, for bulk specimen the small alternating magnetic field of primary coils of amplitude about 10 mOe rms is screened completely by the metallic and/or superconducting surface and does not penetrate to the interior of the specimen yielding the strong diamagnetic signal close to $-(4\pi M)^{-1}$ value. However, the intergrain material is not effectively superconducting (or is weakly superconducting — the so-called weak superconducting links) and that is why even very small external magnetic flux penetrates easily to the bulk specimen through the intergrain boundaries and the field is much lower than the intrinsic inside-grain lower critical field H_{c1}. That is why the best method to measure the intrinsic $H_{c1}(T)$ behavior is to carry out the measurements for a powdered sample, not for the bulk one. If the specimen will be powdered, then the intergrain structure is destroyed and then the a.c. field is less screened and hence the smaller negative diamagnetic signal response $\chi'_{H=0}$

appears. Now, the applied steady magnetic field is pushed out from the particular separated grains being in the Meissner state and does not penetrate throughout the intergrain regions. Hence, for powdered specimen it is possible to measure intrinsic H_{c1} value. The conventional resistivity measurements are then excluded for this purpose, because one has to perform them for bulk specimens. We measured a.c. susceptibility as a function of T and H for powdered specimens in order to elucidate the $H_{c1}(T)$ characteristic. The results are shown in Fig. 2 for both the bulk and powdered specimens. Figure 3 shows the specific plot for 61 K and the low field data in enlarged scale in order to see the method of determination of H_{c1}.

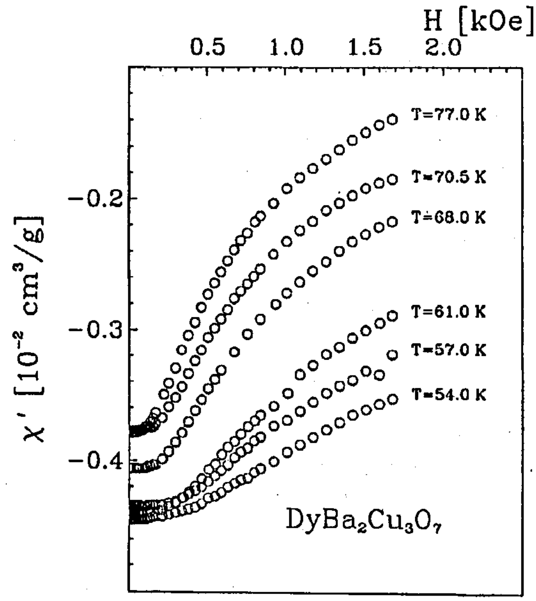

Fig. 2. The field dependencies of a.c. susceptibility of $DyBa_2Cu_3O_{\sim 7}$ for the fine powdered specimen at the given temperatures.

The method of determination of H_{c1} from a.c. susceptibility is as follows. The Meissner state diamagnetic magnetization is linear function of applied magnetic field $\boldsymbol{M} = -\boldsymbol{H}$, up to the lower critical field H_{c1} and then the χ' value should be constant. Therefore, the H_{c1} is defined as a maximal field for which the χ' value is still fixed. This constant value of χ' is seen in enlarged scale in the insert of Fig. 3 together with the definition of $H_{c1'}$. From Fig. 3 one can see that such constant value does exist for properly powdered specimen (curve 3) but not for bulk specimen (curve 1). Also for crush powdered specimen (curve 2) the constant value of χ' does not correspond to the lower critical field yet. Most likely, better powdered specimen is better determined than the intrinsic lower critical field is. This is due to the granular effect.

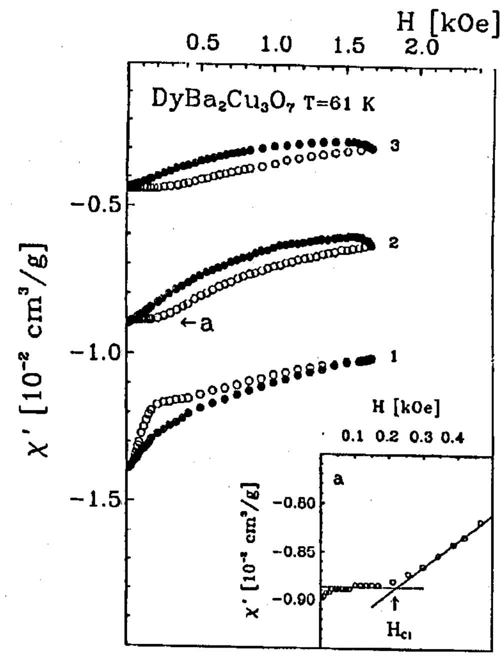

Fig. 3. The field dependencies of a.c. susceptibility of $DyBa_2Cu_3O_{\sim 7}$ for the bulk specimen — 1, for the crush powdered specimen — 2, for the fine powdered specimen — 3, with the increasing field (o) and the decreasing field (•) at the given temperature. The insert "a" shows the same dependence in enlarged scale together with the definition of H_{c1}.

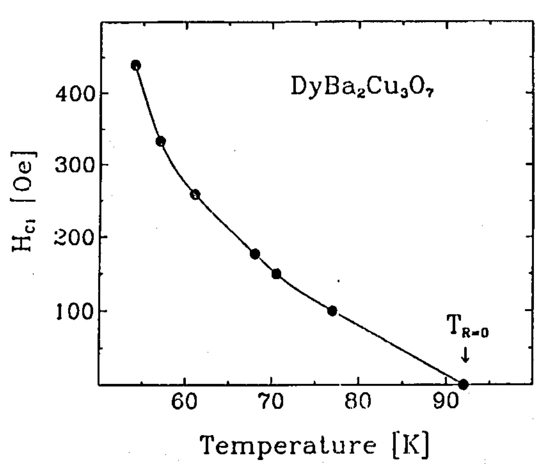

Fig. 4. The temperature dependence of lower critical field of $DyBa_2Cu_3O_{\sim 7}$.

The plot of $H_{c1}(T)$ is shown in Fig. 4. The values of H_{c1} are always about two times larger than the values obtained for bulk specimen or even single crystals. This is in agreement with our earlier suggestion about the absence of the granular effect for powdered specimen and then always H_{c1} is larger than for bulk specimen with granular effect in.

According to the Ginzburg–Landau–Abrikosov–Gorkov (GLAG) theory the $H_{c1}(T)$ dependence together with the γ, T_c and resistivity values are quantities sufficient to calculate other superconducting and normal-state parameters. This will be done in what follows. One can also use for that purpose the temperature dependence of upper critical field $H_{c2}(T)$ in the vicinity of T_c instead of $H_{c1}(T)$. This is even more commonly used method. But our $H_{c2}(T)$ dependence originates from magnetoresistance measurements and then it is again affected very much by the granular effect and thus not useful. We will explain this fact later on, comparing our magnetoresistance measurements and the $H_{c2}(T)$ data for $DyBa_2Cu_3O_7$ specimen with calculated values of $H_{c2}(0)$ and the slope $(dH_{c2}/dT)_{T_c}$ from GLAG theory. Figure 5 shows some selected magnetoresistance data $R(H,T)$ and the $H_{c2}(T)$ dependence in its insert for $DyBa_2Cu_3O_7$.

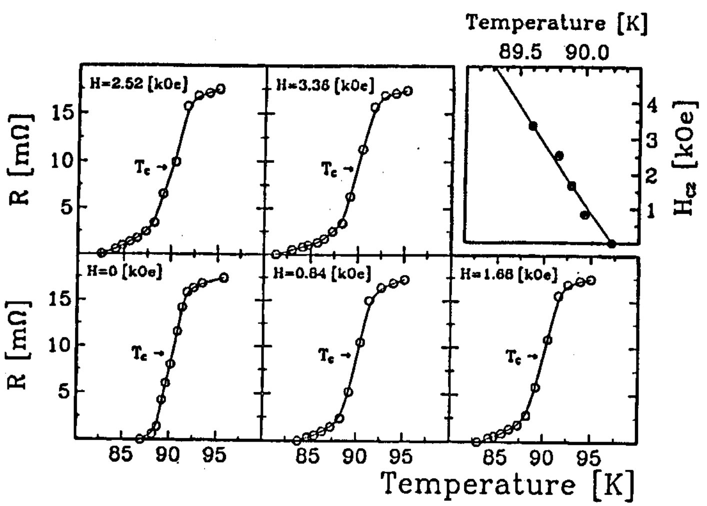

Fig. 5. The temperature dependencies of resistance R at the given magnetic field H together with the temperature dependence of upper critical field H_{c2} in upper right corner.

3.2. Specific heat

The experimental results of specific heat measurements for semi-adiabatic and continuous heating runs were collected in the form of C/T as a function of temperature, where C is the measured total specific heat. The specific heat jump at $T_c = 91.4 \pm 0.1$ K equals to about 6% of the total specific heat which is rather large in comparison to other observations [11].

We analyzed the specific heat data in the vicinity of T_c taking into account also the Gaussian fluctuations and following the formula derived in [12]. The detailed analysis of our data for $DyBa_2Cu_3O_7$ is described elsewhere [9] according to the formula

$$C/T = a + bt + 1.43\gamma(1 + 1.83t) + C_{\mp}/T(\mp t)^{-1/2},$$

where $t = TT_c^{-1} - 1$, γ is the electronic specific heat coefficient, a and b are the coefficients of the linear temperature dependent background mainly of the lattice specific heat, $C_{\mp}$ are the coefficients of Gaussian fluctuations terms below ($-$) and above ($+$) T_c and the third term describes the BCS-like contribution to the specific heat. Here, we want only to present in Fig. 6 the result of our fitting procedure [9] of the experimental data to the formulas (1) from which we calculated the electronic specific heat coefficient γ as equal to

$$\gamma = 38.2 \pm 0.5 \text{ mJ mol}^{-1} \text{ K}^{-2}.$$

The γ-coefficient is the important electronic quantity of which we are going to

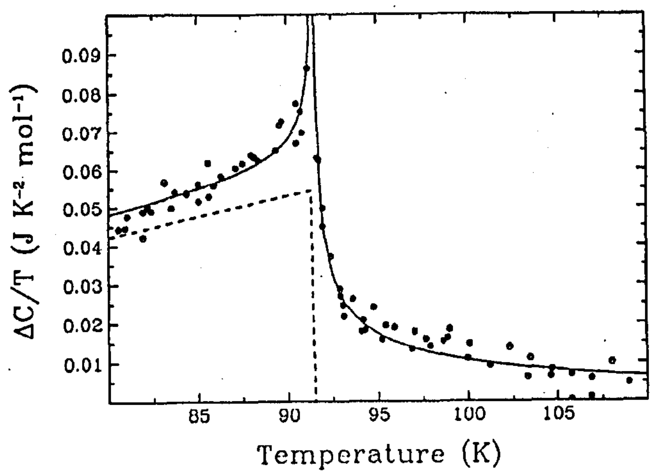

Fig. 6. The calculated temperature dependence of BCS (dashed line) and of BCS plus fluctuating contribution (solid line) of electronic specific heat fitted to the experimental data of $DyBa_2Cu_3O_{\sim 7}$ (•) [9].

take advantage in further calculations. This γ value yields the density of electronic states at the Fermi level equal to

$$N(E_F) = (2\pi^2 k_B^2)^{-1}\gamma \approx \begin{cases} 0.6 \text{ states (spin, eV, at.)}^{-1}, \\ 7.4 \text{ states (spin, eV, f.u.)}^{-1}. \end{cases}$$

4. Electronic properties of superconducting and normal states

From the γ and T_c values together with the $H_{c1}(T)$ dependence close to T_c and the measured low temperature normal-state resistivity ρ several important superconducting and normal-state material parameters may be calculated. These calculations are based on the evaluation of the Ginzburg–Landau (GL) parameters from Abrikosov's extension of the Ginzburg–Landau theory and from the BCS–Gorkov equations near T_c. This is the so-called Ginzburg–Landau–Abrikosov–Gorkov (GLAG) theory of type-II superconductors and the most useful formulae are elaborated in [13]; they have the following form for an isotropic superconductor:

1. The temperature dependence of lower critical field $H_{c1}(T)$:

$$H_{c1}(T) = H_c(T)\ln\kappa(2^{1/2}\kappa)^{-1}. \qquad (1)$$

2. The thermodynamic critical field $H_c(T)$:

$$H_c(T) = 4.23\gamma^{1/2}T_c(1-t) \text{ with } t = TT_c^{-1}, \qquad (2)$$

where κ is the so-called Ginzburg–Landau parameter κ_{GL}, which combines the superconducting and normal state parameters, and γ is in erg cm^{-3} K^{-2}.

3. The temperature dependence of upper critical field $H_{c2}(T)$:

$$H_{c2}(T) = 2^{1/2}\kappa H_c(T). \qquad (3)$$

Therefore, both temperature dependencies $H_{c1}(T)$ and $H_{c2}(T)$ are linear functions of the temperature close to T_c, where the G–L theory is valid. This is really the case for our experimental results seen in Fig. 4 for $H_{c1}(T)$ and in Fig. 5 for $H_{c2}(T)$. An additional comment here is that a new approach to the theory of HTS through the so-called local pairing theory gives also the proper description of $H_{c1}(T)$ in the linear form against temperature [14]. Thus, we believe that the dependence of $H_{c1}(T)$ is intrinsic quantity for superconducting grains of HTS and that the dependence may be compared to the theory.

Therefore, we calculated the κ value from the linear part of the experimental $H_{c1}(T)$ dependence according to Eq. (1) as equal to

$$\kappa = 91.5 \pm 3. \qquad (4)$$

Then, the values of H_{c2} calculated from Eq. (3) as well as the slope of upper critical field $(\mathrm{d}H_{c2}/\mathrm{d}T)_{T_c} = -5.96\gamma^{1/2}\kappa$ Oe K^{-1} in the vicinity of T_c is always too large in comparison to the experimental values presented in Fig. 5. For example, the calculated slope is ten times smaller -0.425 T K^{-1}. The reason may be due to the circumstance that the measured values of $H_{c2}(T)$ are not intrinsic feature of HTS due to the granular effect of bulk specimen (cf. also the previous paragraph).

Taking into account the κ value from Eq. (4) as the Ginzburg–Landau parameter κ_{GL}, one can calculate a number of superconducting and normal-state quantities; this is because the parameter κ_{GL} has the form [13]:

$$\kappa_{GL} = [1.6\times10^{24}T_c\gamma^{3/2}(n^{2/3}SS_F^{-1})^{-2} + 8.78\times10^{3}\gamma^{1/2}\rho][R(\lambda)]^{-1}, \qquad (5)$$

with γ in erg cm^{-3} K^{-2}, the conduction-electron density n in cm^{-3}, the average Fermi surface S and the Fermi surface of an electron gas of density n, S_F, in cm^{-2}, and the low-temperature normal-state resistivity ρ in Ω cm. $R(\lambda)$ is the so-called Gorkov's function with $R(0) = 1$ and $R(\infty) = 1.17$. The parameter λ is the so-called Gorkov parameter defined by the BCS coherence length ξ_0 and the mean free path length l as $\lambda = 0.882\xi_0 l^{-1}$. Thus, one can calculate from Eq. (5) the normal state quantity $n^{2/3}SS_F^{-1}$ because in addition to the γ and T_c values the measured ρ value is 250 $\mu\Omega$ cm and one can take into account the average value of $R(\lambda) = 1.08$, which does not affect much the calculated values.

A number of superconducting and the normal-state electronic quantities was determined because they are always expressed by the above quantity $n^{2/3}SS_F^{-1}$ and the function $R(\lambda)$, or equivalently, by the BCS coherence length ξ_0, the London penetration depth λ_{Lo} and the Gorkov parameter λ, which have the expressions

$$\xi_0 = 7.95 \times 10^{-17} n^{2/3} SS_F^{-1} (\gamma T_c)^{-1} \text{ cm}, \tag{6}$$

$$\lambda_{Lo} = 1.33 \times 10^{8} \gamma^{1/2} n^{2/3} SS_F^{-1} \text{ cm}, \tag{7}$$

$$\lambda = 0.882\xi_0 l^{-1} = 5.51 \times 10^{-21} \rho n^{2/3} SS_F^{-1} (\gamma T_c)^{-1}, \tag{8}$$

and

$$l = 1.27 \times 10^{4} (\rho n^{2/3} SS_F^{-1})^{-1} \text{ cm}. \tag{9}$$

Additional GL parameters are calculated for $t = 0$ and according to formulae [13]:

$$\xi_{GL} = 0.739\xi_0 (1+\lambda)^{-1/2} [R(\lambda)]^{1/2} (1-t)^{-1/2} \text{ cm}, \tag{10}$$

$$\lambda_{GL} = 2^{-1/2} \lambda_{Lo} (1+\lambda)^{1/2} [R(\lambda)]^{-1/2} (1-t)^{-1/2} \text{ cm}. \tag{11}$$

Also, the Fermi velocity

$$v_F = 5.8 \times 10^{-5} n^{2/3} SS_F^{-1} \gamma^{-1} \text{ cm}^{-1} \text{ s}^{-1} \tag{12}$$

and the superconducting energy gap

$$\Delta E_s = 2\hbar v_F \pi^{-1} \xi_0^{-1} \text{ erg} \tag{13}$$

were estimated. The full list of calculated quantities is presented in Table.

The most striking conclusion coming from our analysis of the experimental data is that we obtained a reasonable and consistent set of superconducting and normal-state microscopic electronic parameters within the frame of GLAG theory which is the BCS-like electron–phonon mediated interaction theory. Namely, starting from the four measured quantities, i.e. $H_{c1}(T)$, T_c, γ, and ρ, we have got the values of $\kappa_{GL} = 91.5$, $\xi_{GL} = 9$ Å and $\lambda_{GL} = 1300$ Å which are comparable to other independently estimated or measured values cited in literature. The κ_{GL} value is very large for HTS and always about 100 which means that the upper critical field is much larger than the lower critical field because $H_{c2}/H_{c1} = 2\kappa^2(\ln\kappa)^{-1}$ and that the penetration depth λ_{GL} is much larger than the coherence length ξ_{GL} because $\kappa_{GL} \approx \lambda_{GL}/\xi_{GL}$. The same holds for the ratio of the upper to the lower critical-field slopes. The value of ξ_{GL} is very small for the HTS in comparison to the low-temperature superconductors of which the ξ_{GL} values are always one or two orders of magnitude larger.

The calculated value of slope of the upper critical field $(\mathrm{d}H_{c2}/\mathrm{d}T)_{T_c}$ is also comparable with other experimental observations on both single crystals and polycrystals, but in the latter case the slope ought to be determined from magnetization measurement for a powdered sample. We have mentioned above why the

TABLE

Superconducting and normal state electronic properties of $DyBa_2Cu_3O_7$.

Superconducting state	
Parameter	Value
Superconducting transition temperature, T_c	$= 91.4 \pm 0.05$ K [a]
Ginzburg–Landau (GL) parameter, κ	$= 91.5$ [c]
Thermodynamic critical field, $H_c(0)$	≈ 20.1 kOe
Lower critical field, $H_{c1}(0)$	≈ 700 Oe
Upper critical field, $H_{c2}(0)$	≈ 2600 kOe [e]
$(dH_{c2}/dT)_{T_c}$	≈ -42.3 kOe K^{-1}
GL penetration depth, $\lambda_{GL}(0)$	≈ 1300 Å
GL coherence length, $\xi_{GL}(0)$	≈ 9 Å
London penetration depth, λ_0	≈ 370 Å
BCS coherence length, ξ_0	≈ 60 Å
Gorkov parameter, λ	$= 0.882\xi_0 l^{-1} \approx 24$
Superconducting energy gap, ΔE_s	≈ 28 meV
Normal state	
Parameter	Value
Electronic specific heat coefficient, γ	$= 38.2 \pm 0.5$ mJ mol^{-1} K^{-2} [b]
Low-temperature resistivity, ρ_{100K}	$= 250$ $\mu\Omega$ cm [d]
Debye's temperature, Θ_D	$= 412$ K [b]
Density of states at E_F, $N(0)$	≈ 7.4 states (spin, eV, f.u.)$^{-1}$
Mean free path, l	≈ 2.2 Å
Average Fermi velocity, v_F	$\approx 4 \times 10^7$ cm s^{-1}
Conduction electron density, n	$\approx 3 \times 10^{21}$ cm^{-1} for $S/S_F \approx 0.5$
Ratio of Fermi surface to Fermi surface of electron gas of density n, $n^{2/3}S/S_F$	$\approx 1.88 \times 10^{13}$ cm^2
Electron–phonon interaction parameter, λ_{e-p}	≈ 4 [f]
Fermi energy, E_F	$= 0.02$ eV

[a] The midpoint resistive transition temperature.

[b] From specific heat measurements with the Gaussian fluctuation included.

[c] From fitting of $H_{c1}(T) = H_c(T)\ln\kappa(\sqrt{2}\kappa)^{-1}$ to the experimental data, where $H_c(T) = 4.23\gamma^{1/2}T_c(1-t)$ Oe.

[d] As measured at 100 K.

[e] From $H_{c2}(T) = \sqrt{2}\kappa H_c(T)$.

[f] From $T_c = 0.34\Theta_D \exp(-2/\lambda_{e-p})$ [15].

slope extracted from magnetoresistance measurements for bulk specimen is always smaller than the calculated value $(dH_{c2}/dT)_{Tc}$ because of the granular effect. The huge value of the Gorkov parameter λ means that in the case of HTS we always deal with the dirty limit of superconductivity according to the criterion $\lambda \gg l$. Finally, also the value of the calculated superconducting energy gap ΔE_s matches the observed values in tunneling experiments.

As far as the calculated normal-state quantities are concerned one could notice the reasonable value of $n^{2/3}SS_F^{-1}$. This yields the reliable value of $n \approx 3 \times 10^{21}$ electrons per cm^3 for electron gas density even with assumption of a spherical Fermi surface S_F corrected by the ratio $0 < S/S_F \leq 1$ which we have taken as equal to 0.5. Also, the density of states at the Fermi energy $N(0)$ and the calculated mean free path l seem to be very close to what one can expect for HTS. However, the Fermi energy E_F:

$$E_F = (\pi^2 k_B/3)n/\gamma$$

is very small and it has already been argued that it is an intrinsic and characteristic electronic property of HTS's [16].

One can also analyze our data with the help of an anisotropic GLAG theory [17], taking into account the anisotropy of the coherence lengths in HTS, $\xi_{\|c} \leq \xi_{\perp c}$, of the lower and the upper critical fields, $H_{c1\|c} > H_{c1\perp c}$ and $H_{c2\|c} > H_{c2\perp c}$, as well as of the resistivity $\rho_{\|c} > \rho_{\perp c}$. A preliminary comparison of single crystal data for $Bi_2Sr_2Ca_1Cu_2O_8$ with the anisotropic GLAG theory will be published elsewhere. Nonetheless we checked that the results of such anisotropic approach do not change the general conclusion that our experimental results for $H_{c1}(T)$, γ, T_c, and ρ may be consistently described by the usual BCS–GLAG theory. This does not mean in any way that we are in position to say that the crucial pairing mechanism comes from the electron–phonon interaction. This rather means that any pairing mechanism or any other attractive electron (hole) interaction which could be responsible for high-temperature superconductivity should yield similar theoretical relationships between the discussed quantities as in the BCS theory.

4. Conclusions

We measured the temperature dependence of resistance, magnetoresistance, specific heat and a.c. susceptibility for $DyBa_2Cu_3O_7$. For fine powdered sample we were able to determine the temperature dependence of lower critical field $H_{c1}(T)$. Then, in combination with specific heat data on γ value and ρ value, a number of superconducting and normal-state electronic quantities were calculated on the basis of the GLAG theory. The conclusions coming from such analysis of the experimental data are threefold.

1. In order to obtain the reliable and consistent description of the data one has to take into account the intrinsic characteristic of $H_{c1}(T)$ measured for the powdered specimen but not the granular-dependent characteristic of $H_{c2}(T)$ of the magnetoresistance measurements for the bulk specimen.

2. Taking into account T_c, γ, ρ, and $H_{c1}(T)$ from experiment the calculated quantities within the frame of GLAG theory, such as: κ_{GL}-parameter, $H_{c2}(T)$,

ξ_0, λ_{Lo}, λ-parameter, ξ_{GL}, λ_{GL}, v_F, ΔE_s, n, and l, form a very reasonable set of values which are expected to be reliable for HTS and are comparable to the other independent experimental findings and theoretical estimations.

3. The fact that the GLAG theory fits the experimental data does not have to mean that the electron–phonon interactions are a driving mechanism, but may mean that any other theory which will claim to describe HTS might have similar or the same relationships among the basic superconducting and normal-state physical quantities characterizing HTS.

Acknowledgments

This work is supported financially by the Committee for Scientific Research.

References

[1] J.R. Kirtley, *Int. J. Mod. Phys. B* 4, 201 (1990).

[2] Z. Schlesinger, R.T. Collins, F. Holtzberg, C. Feild, N.E. Bickers, D.J. Scalpino, *Nature* **343**, 242 (1990).

[3] M.B. Salamon, in: *Physical Properties of High Temperature Superconductors I*, Ed. D.M. Ginsberg, World Scientific, Singapore 1989, p. 39.

[4] M.N. Keene, T.J. Jackson, C.E. Gough, *Nature* **340**, 210 (1989).

[5] T. Gordon, P. Collman, W.A. Little, *Physica C* **161**, 195 (1989).

[6] L. Krusin-Elbaum, R.L. Greene, F. Holtzberg, A.P. Malozemoff, Y. Yeshurun, *Phys. Rev. Lett.* **62**, 217 (1989).

[7] J. Chmist, Thesis, University of Mining and Metallurgy, Kraków 1991.

[8] Z. Tarnawski, Thesis, University of Mining and Metallurgy, Kraków 1986.

[9] A. Kozłowski, Z. Tarnawski, A. Kołodziejczyk, J. Chmist, T. Ścieżor, R. Zalecki, *Physica C* **184**, 113 (1991).

[10] G. Deutscher, in: *Earlier and Recent Aspects of Superconductivity, Springer Series in Solid-State Sciences*, Vol. 90, Eds. J.G. Bednorz, K.A. Müller, Springer, Berlin 1990, p. 174.

[11] J.E. Braun, R.A. Fisher, S. Kim, N.E. Phillips, *Physica C* **162-164**, 484 (1989).

[12] S.F. Inderhees, M.B. Salamon, Nigel Goldenfeld, J.P. Rice, B.G. Pazol, D.M. Ginsberg, J.Z. Liu, G.W. Crabtree, *Phys. Rev. Lett.* **60**, 1178 (1988).

[13] T.P. Orlando, M.R. Beaslay, *Phys. Rev. Lett.* **46**, 1598 (1981).

[14] R. Micnas, J. Ranninger, S. Robaszkiewicz, *Rev. Mod. Phys.* **62**, 113 (1990).

[15] M. Surma, *Phys. Status Solidi B* **116**, 465 (1983).

[16] J. Yu, A.J. Freeman, *J. Phys. Chem. Solids* **52**, 1351 (1991).

[17] V.L. Ginzburg, *Physica C* **153-155**, 1617 (1988).